

**Integrated Communications, Navigation, Surveillance
(CNS) Technology Workshop
Cleveland, Ohio
May 1, 2001**

**Keynote Address
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Introduction

While I was thinking about how to introduce my remarks tonight, the thought that occurred was to tell the truth about why it seems a little awkward for me to be standing in front of you speaking instead of me sitting where you are and listening to someone else.

That truth can be best stated by the following description of the state in which I find myself these days. That description would go something like this:

“Middle aged aerodynamicist . . . strong interest in transportation . . . seeks a position in the Information Age.”

So, my hope is to offer some thoughts that cross these unusual boundaries and perhaps stimulate some dialogue within your workshop.

In a previous life, I was able to shed some light in the darkness on the subject of the airframe surface manufacturing tolerances for stable compressible laminar shear layers – high tech aerodynamics stuff of the waning days of the industrial age. And now I find myself exploring the meaning of a different kind of light, the light of Maxwell’s Rainbow if you will, and its role in transportation. Specifically, I would like to share some thinking about the subject of the meaning of the revolution in digital bandwidth to the future of the way we travel in the 21st century.

Before I talk about some of the laws and rules of thumb that guide this revolution . . .

But before I discuss these rules, remember the 1967 movie in which Dustin Hoffman played Benjamin, the Graduate, and Ann Bancroft played Mrs. Robinson? At the party, a friend of the family took the young man aside and said that golden word: PLASTICS! How would that movie be done today? Instead of Dustin Hoffman, would Drew Carey played the graduate? Who would play Mrs. Robinson? What would be the golden word today? The answer to that question is: BANDWIDTH!

- Here are the laws and rules of thumb that motivate our 21st century thinking:
- Computing power will increase at the rate of doubling every 18 months or so, according to Moore’s Law
- Communication power will increase at the rate of doubling every 6 months or so, according to Gilder’s Law¹

¹ Gilder, George: Telecosm. The Free Press, NY, NY, 2000.

- The value of a network is proportional to the square of each terminal's processing power, according to Metcalfe's Law²
- In digital theory, for all practical purposes we have infinite bandwidth; from the Johnson Noise thermal frequency of the deep space background characteristic to gamma rays represents about ten to the 25th hertz in spectrum. We use a tiny fraction of physical bandwidth, largely in analogue form. We do not have science-backed policy for managing spectrum using time-domain thinking; all of our practices, protocols and paradigms are arranged to support frequency-domain spectrum management.
- The rule of any age is to waste that which is in abundance to solve human problems. Just as in the agricultural age, we could waste abundant land to solve the need for food, in the information age; we should imagine wasting bandwidth to solve modern problems, including those in transportation. I realize that such an approach sounds heretical to those of us in technology who learn to economize, streamline, and simplify as the basis of sound engineering practice. One look at a Saturn V can be convincing that we didn't get to the moon by economizing on ISP (specific impulse of rocket motors).
- The unwritten rule of gridlock is that added highway lane miles create more demand than they were designed to relieve. An interesting dialogue unfolded during the last week that I was working at the White House in March, between Transportation Secretary Mineta and his new boss, President Bush. "Get the airport congestion and delays problem off the front pages," was Bush's admonishment to Mineta. Building more runways seems to be our only response at present.
- What does that mean about building more runways to solve the problem of delays at our nation's large airports? There is no doubt that we need the new runways, the sooner the better. However, there is also no doubt that these new runways (ten or so in the next 15 years, at a cost of about \$15 billion) will not solve the long-term problem. The rule of gridlock should teach us the simple lesson that adding more runways will increase demand to a greater level than those runways are being designed to serve. One common law definition of insanity is continuing to do what we've been doing, expecting to get a different result. What's wrong with this picture?
- Hub-and-spoke delays will grow hyperbolically (at least until the physical constraints of gates and runway occupancy time kick in), according to Donohue's Law (with apologies to George). The hub-and-spoke system could perhaps stabilize in performance (delays) in a limit-cycle characteristic of second-order dynamic systems. However, even once that were to occur, the system behavior would continue to be oscillatory, with periods of delays and on-time behavior cycling in response to any disturbances (weather, labor, equipment, or security threats). An on-demand, distributed transportation system, one that does not possess second-order dynamic behavior triggered by system delays or other disturbances, might possess first-order dynamic responses. Such system behavior might be vastly preferable to travelers. In addition, such a distributed, on-demand system might possess highly preferable resistance to security threats (including terrorism).
- The golden rule of this age is that time is gold. In the same ways that horsepower was the defining scarcity of the agricultural age, time is the new defining scarcity of this age. And

² *Ibid.*

like manpower and land were the defining abundances of the agricultural age, bandwidth, MIPS and KBPS are the defining abundances of the information age. Those individuals, companies, and societies that comprehend this rule will thrive in this age.

I see these laws and rules of thumb as the motive forces that can change the way we as Americans travel and ship in the 21st century. Clearly, the Nation's transportation system is reaching a crossroads. Current investment strategies in solving the challenges of gridlock in the air, as well as on the ground are not sufficient to satisfy burgeoning demand. Even after we have poured concrete, closed spacing, and enforced economic behavior, we will still fall short of meeting growing demand for travel and freight.

If there is some good news in this situation, some of it comes from the emerging technologies of the revolution of the micro-world and the revolution in digital bandwidth. How can bandwidth save transportation?

I am going to suggest that because of a new generation of technologies, including the revolution in digital bandwidth, and a new generation of emerging industry leaders, we are in a unique position to conceive innovative alternative concepts for air transportation systems. These innovations have the potential to give Americans new choices in the way we travel, how our products are delivered, and the ways our services (*e.g.*, health care, education, maintenance, emergency services, law enforcement, and other public service functions) are transported in the 21st Century. I will also suggest that the lessons of The Innovators Dilemma³ are highly relevant to all of us in the business of transportation system technologies and strategies. Those lessons make clear the dominant role of down-market moves by new entrant firms operating in new value networks, as the basis for creating alternative solution paths toward market and system innovations.

One such innovation would be to figure out how to make any location on the surface of the nation accessible in three dimensions (four, if we include time). What combination of air vehicle and digital airspace infrastructure (or e-frastructure) would give us the ability to position multiple vehicles safely throughout such airspace? Can the same effects that bandwidth has on the power of network performance in telecommunications (Metcalf's Law) and the Internet us to have networked, distributed, ubiquitous air mobility?

One NASA program to start down this path of research is the NASA Small Aircraft Transportation System Program (SATS⁴). SATS is funded starting in FY 2001 as a five-year proof of concept for specific operating capabilities for small transportation aircraft operating at small airports. SATS technology investments, once implemented, will enable on-demand, point-to-point, high-speed personal air transportation between suburban, rural, and remote communities served by over 5, 000 public-use landing facilities distributed throughout the nation.

The conceptual end-state for truly distributed and ubiquitous on-demand air accessibility is fundamentally enabled by the revolution in digital bandwidth. System dynamics teaches us that this future will take half of this century to unfold. The history of innovation teaches us that we cannot predict what exact forms this transportation capability will take or how people and organizations will use it. Our human limitations teach us that our ability to innovate is

³ Christensen, Clayton: The Innovators Dilemma. Harvard Business School Press 1997.

⁴ Small Aircraft Transportation System (SATS). See <http://sats.nasa.gov/>.

constrained by our idea that innovation is to simply remake the past ... only better. So, how would a future look that was different than merely making the past merely better?

Background

As one great American Sage, Yogi Berra, pointed out, “Prediction is a risky thing, especially when it’s about the future!” Witness some fine prognostications such as:

- “Who the hell wants to hear actors talk?” (H.M. Warner of Warner Brothers, 1927).
- “The problem with television is that the people must sit and keep their eyes glued on a screen; the average American family hasn’t the time for it.” (The New York Times article about the debut of TV at the 1939 World’s Fair).
- And one of my favorites, “640K ought to be enough for anybody,” from Bill Gates.
- At the end of my remarks tonight, I would like to offer a prediction, fully aware of the potential future risk of shortsightedness.

During the 19th Century, automobiles and roads democratized travel for Americans, in a two dimensional world. In a sense, one could say that the automobile put wheels on America in the last century. The result was that economic opportunity was no longer confined to the nation’s 19th century seaports, riverports and railheads. The force behind this industrial age revolution was the plummeting price, coupled with the soaring abundance of power (in the form of horsepower and kilowatts). As the industrial age comes to a close, we are crossing the threshold into the information age. During this new age, previous paradigms, in either transportation or bandwidth, will not satisfy 21st century needs nor stimulate 21st century opportunities.

In the 21st Century, the opportunity is emerging for democratized travel in three-dimensional air space, far beyond the constraints of the existing hub-and-spoke airport and interstate highway systems. In a sense this vision would put wings on America. The result would be economic opportunity that is not limited to the 20th century interstates and hub-and-spoke airports. The force behind the information age is the revolution in digital bandwidth and the plummeting price, coupled with the soaring abundance, of the microcomputer and telecommunications technologies.

As our existing infrastructure of interstates and hubs-and-spoke airports reach maturity and saturation, a paradox is unfolding. The paradox is that away from the 540 hub-and-spoke airports, capacity at over 5,400 public use airports is abundant. As with digital bandwidth, we only use a tiny fraction of our potential capacity, perhaps as little as a few percent. In addition, our nation has an existing infrastructure of over 18,000 landing facilities that represent an untapped capacity reserve. Unfortunately, only about 10% of our public airports have precision instrument guidance, communications, and radar coverage for safe and accessible near-all-weather operations.

It may surprise many to learn that for trips of less than 500 miles, the average speed from doorstep to destination is between 35 and 80 miles per hour in the hub-and-spoke system. The bad news is that as congestion increases, these speeds will assuredly decrease in the future. While we must invest in technologies for the hub-and-spoke system, along with investing in new runways, and developing economic incentives for management of demand, the reality is that

demand will continue to soar beyond supply, even after we have made all of these important investments. Whether in the air or on the ground, gridlock will constrain economic opportunity in the information age.

The good news is that as a result of the past 7 years of publicly funded NASA investments in technology for aircraft, a new generation of safe and affordable aircraft is emerging. These NASA investments were made through the Advanced General Aviation Transport Experiments (AGATE) Alliance and the General Aviation Propulsion (GAP) Program. Coupled to the Generation Aviation Revitalization Act of 1994 and burgeoning market demand, these technology investments have supported the following industrial recovery over the past five years (1995-2000):

- more than 300% growth in aircraft deliveries
- more than 350% growth in industry billings
- over 20% improvement in fleet safety
- recovery to about 20% of export deliveries
- about 10% annual growth of jobs in sector

The enabling technologies from the AGATE and GAP investments include:

- New turbine engines with revolutionary thrust-to-weight and cost metrics
- Commercial Off The Shelf (COTS)-based avionics with vast improvements in cost, reliability, and capabilities
- Highway-In-The-Sky (HITS) graphical pilot guidance systems
- New approaches to crashworthiness
- Streamlined composite airframe manufacturing techniques
- Ice protection technology
- Digital engine controls (for single-lever power control)
- Graphical weather information in the cockpit
- Advanced flight training and pilot certification processes

As a result of the AGATE and GAP investments, several new aircraft are emerging in the marketplace. However, in order that these new aircraft can serve the American traveling public, new concepts for airspace use and operation are needed. These new concepts will be underwritten by the bandwidth revolution.

Suburban, small, rural and remote communities represent the stakeholders and major beneficiaries of this research. The end result will be safe, nearly all-weather access to any location in the nation with an existing landing facility.

The SATS Program

The Congressional budget appropriation for the SATS Program includes a mandate to “prove SATS works.” This mandate includes demonstration of four operational capabilities, enabled by the integration of emerging technologies from two previous NASA-industry programs, AGATE⁵ and GAP⁶. These four capabilities are:

- (1) Higher-volume operations at airports without control towers or terminal radar facilities
- (2) Lower adverse weather landing minimums at minimally equipped landing facilities
- (3) Integration of SATS aircraft into a higher en route capacity air traffic management system with complex flows and slower aircraft; and
- (4) Improved single-pilot ability to function competently in complex airspace

NASA will facilitate the formation of a public-private alliance to encompass state-based partnerships for the execution of the SATS Program. These partnerships will participate in continued technology development, system analysis and assessment, technology integration and flight demonstrations of the SATS operating capabilities.

The enabling technologies, developed initially under the AGATE and GAP programs, will be refined for integration by the SATS Program and will include:

- Integration of Highway-In-The-Sky (HITS) with synthetic vision systems
- Simplified software-based flight controls
- Autoland capability for the SATS class of aircraft
- Automatic Dependent Surveillance-Broadcast surveillance
- Airborne Internet communications
- Computational algorithms for automated traffic separation and collaborative sequencing

These technologies form the foundations for creating the four SATS operating capabilities.

Summary

In summary, the Nation is now in a unique position to create the next big thing in consumer choices for personal or business air transportation, shipment of goods, and delivery of services. This opportunity to innovate comes at a time when existing air and ground infrastructures are maturing and reaching saturation. Without alternatives to existing systems, the economic opportunities of the Information Age will be constrained to existing transportation infrastructures. With alternatives, new patterns of economic opportunity are enabled that need not be constrained the 20th century hub-and-spoke airport and interstate highway infrastructures.

The vision for a truly distributed and ubiquitous system of on-demand air mobility has the potential to catalyze the Nation’s economic development in the Information Age. How does the

⁵ Advanced General Aviation Transport Experiments (AGATE) Alliance and research program. See <http://agate.larc.nasa.gov/>.

⁶ General Aviation Propulsion (GAP). Website link available from <http://agate.larc.nasa.gov/>.

revolution in digital bandwidth save transportation? I suggest that the possibility for this to happen is driven by the same underlying effects of bandwidth that create the power of networks in the internet and the telecommunications e-frastructure. The outcome will be truly distributed and ubiquitous accessibility in air transportation.

I promised at the end of my remarks tonight, to offer a prediction of my own. At the risk of being shortsighted, here it is: “18K (airports) ought to be enough for everyone.”